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Discrimination in the use of radar data adjusted by sparse gauge observations for determining surface rainfall

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Summary

Dense radar observations of a rainfall field can be adjusted by sparse gauge observations to estimate the surface rainfall at an ungauged location as an alternative to a direct interpolation between the gauge observations. It is demonstrated that it is possible to choose which of the estimates — gauge-only or adjusted radar — is closest to the unknown true gauge value with a success rate of correct choice of more than 50%. The purpose of choosing is to prevent the indiscriminate use of radar observations and to reduce the possibility of them being used under circumstances in which it would be non-beneficial.

1. Introduction

The Advisory Services Branch (Met O 3) of the Meteorological Office has a requirement for estimating surface rainfall amounts at ungauged locations for a range of durations from five minutes to a year. In the past this has been carried out by direct interpolation between gauge observations, for instance using the CARP procedure (Shearman and Salter 1975). This process is essential for deriving isohyetal fields, i.e. the spatial distribution of rainfall amount for a specified duration.

For studies of daily or longer period rainfalls well after the event, observations from the climatological network of rain-gauges are usually adequate. The inter-gauge spacing in this network ranges from 3 km to over 30 km depending on locality with an average of about 8 km. For more pressing requirements for daily rainfalls the only observations which are reported in near real time are those available from the synoptic network with gauge spacings ranging from 20 km to 100 km and an average of about 40 km. For observing sub-daily rainfalls, whether reported in real time or historically, the rain recorders are again separated by about 40 km on average with a large range of spacings as above.

Recently, quantitative measurements of rainfall by radar have become available (Palmer *et al.* 1983) and because of their regular and dense coverage (5 km spacing) they have potential as an aid to interpolation especially between widely spaced gauges. Their availability in real time every 15 minutes, and every 5 minutes historically, increases their potential for a range of advisory and research purposes.

The strategy has been adopted in Met O 3 that radar data should be used to aid in estimating by interpolation the surface rainfall which would have been observed by gauges rather than acting as an

Notation

g	gauge measurements
r	radar measurements
g_t	adopted true gauge observation
r_t	adopted true radar observation
g_i	gauge values at corner (i) of square
r_i	radar values at corner (i) of square
g_e	estimate from gauge observations only
r_e	estimate from radar observations only
a_e	r_t adjusted by gauge observations
o_e	optimum estimate, i.e. the better of g_e and a_e
p_e	estimate chosen (either g_e or a_e) by the practical choice method
$\bar{g}$	constant — average g of whole array
S	operator indicating 'standard deviation of'
E_{rg}	$S\{\log(r_t/g_t)\}$
E_{gg}	$S\{\log(g_e/g_t)\}$
E_{ag}	$S\{\log(a_e/g_t)\}$
E_{og}	$S\{\log(o_e/g_t)\}$
E_{pg}	$S\{\log(p_e/g_t)\}$
E_{rr}	$S\{\log(r_e/r_t)\}$
I	inter-gauge spacing
I_a	I at which $E_{rr} \approx E_{rg}$
I_b	I at which $E_{ag} \approx E_{rg}$
I_c	I at which $E_{gg} \approx E_{ag}$
F_1, F_2	parameters for exponential transformations of data
V_g	$\Delta E_{gg}/\Delta I$
V_r	$\Delta E_{rr}/\Delta I$
N_g	percentage of occasions on which g_e is the better estimate
N_{pc}	percentage of occasions on which the better estimate is chosen correctly

entirely independent measure of an 'unknown' true surface rainfall in competition with gauges. However, the indirect way that radar rainfall estimates are produced (May 1983) suggests that a field of radar observations will inevitably deviate from the corresponding field of gauge observations; comparisons of co-located gauge (g) and radar (r) measurements reveal considerable differences in absolute amounts and, more important, in the ratio r/g at neighbouring locations (Collier *et al.* 1983).

Radar observations of rainfall amounts are averages over contiguous 5×5 km squares which need to be ascribed to specific locations. By symmetry the locations are chosen to be the centre of the squares and so the rainfall field as seen by radar is described by a regular array of grid-point values with a spacing of 5 km as in Fig. 1.

Fig. 1 also shows the typical positions of widely-spaced interspersed gauges. Met O 3 has developed a procedure for estimating the point rainfall that would have been measured by a gauge, at any grid point (such as X in Fig. 1), from the radar rainfall at X adjusted by rainfalls observed by a selection of surrounding gauges. The procedure, called PRAGED (Spalding 1984), involves fitting by a least-squares process a suitable two-dimensional surface to the adjustment factors g/r at the selected gauges

and interpolating to estimate g/r at X. This factor multiplies the r at X to give the adjusted radar estimate (a_e).

A simple interpolated estimate (g_e) of the gauge rainfall at X can also be obtained from the selected gauge observations without the use of radar data at all. Two estimates of the rainfall at X are now available and so it is reasonable to ask which of g_e and a_e is the better estimate. The problem is that the true gauge rainfall at X is not known so that a precise objective decision cannot be made (if it was known then the question would not arise anyway).

The requirement then is to develop a practical method of choosing the better estimate, g_e or a_e. Restrictions are adopted so that the method should be entirely objective using no information other than is contained in the radar grid-point and sparse-gauge values of the particular rainfall field for the specified duration. This means that there is no consideration of the type of rainfall involved — localized, uniform widespread, orographic, etc. — and so the method can be applied to any duration in principle.

For the method to be developed it is necessary that suitable detailed rainfall fields are available to act as truth fields. This means that the investigation is limited to the use of daily rainfall fields. There is a difficulty in finding a selection of suitable homogeneous gauge and radar fields to represent the wide range of conditions under which a method of choosing the better estimate would be required to be used. As a consequence only one example of real r and g fields is chosen but it is transformed in a plausible way to simulate a wider range of conditions. Since there is a need to obtain the maximum amount of information from the limited data, the processes of making gauge-only and adjusted radar estimates at X are simulated for networks with a range of gauge spacings positioned around all grid points in the field.

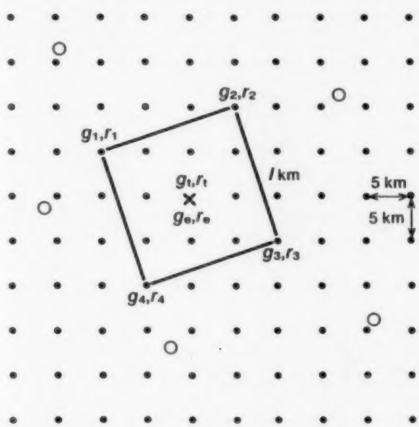

Figure 1. An example of the grid used for radar rainfall data showing simulated interspersed gauges (O). Also shown is a square of sides l km centred on X with the four corner positions used for gauge (g) and radar (r) rainfall values. For explanation of other symbols see text.

2. The data

The radar data used in this investigation are authentic 5 km grid-point daily rainfalls as described previously covering an area of 80 × 80 km (a 16 × 16 array of points) for one day. These radar data have been corrected at source by an on-site calibration but in Met O 3 they are treated as unadjusted data. The

corresponding co-located gauge rainfalls are accurate interpolations to each grid point from a carefully drawn isohyetal pattern based on all gauge observations in the area (amounting to about 100) with a spacing of about 8 km. Since on average the gauges are spaced further apart than the grid points there must be a small degree of correlation between adjacent grid-point values arising from the interpolation involved in contour drawing. It is believed that this is negligible compared with the correlation which exists anyway because of the structure of the rainfall field and does not invalidate the results of this study. In contrast, the radar values at each grid point are independent observations but again are correlated because of the field structure.

These radar and gauge values are referred to as the original values. The isohyets only are plotted in Figs 2 and 3 for clarity. Both radar and gauges showed a well-defined area of heavier rainfall near the centre of the field. In comparison the ratio g/r in Fig. 4 shows a pattern of maxima and minima not obviously related to the rainfall pattern.

3. The analysis

The aim of the first part of the analysis is to use the g and r values in Fig. 1 to simulate the estimation of rainfall by direct interpolation within gauge observations and by the gauge adjustment of radar observations, and to investigate the accuracy of these estimates.

As an example, consider gauge-only estimates. Four grid points ($i = 1,2,3,4$) at the corners of a square of side l km centred on the grid point X are chosen where l is identified with the inter-gauge spacing in a sparse network as in Fig. 1. At any grid point within the square it is possible to make an estimate, using the four corner values (g_i), of the rainfall which would have been observed by a gauge for comparison with the true gauge rainfall (g_t). The smallest square of interest has only one internal point and this is at the centre, so all comparisons are limited to the centre point of all squares of whatever size. This has the

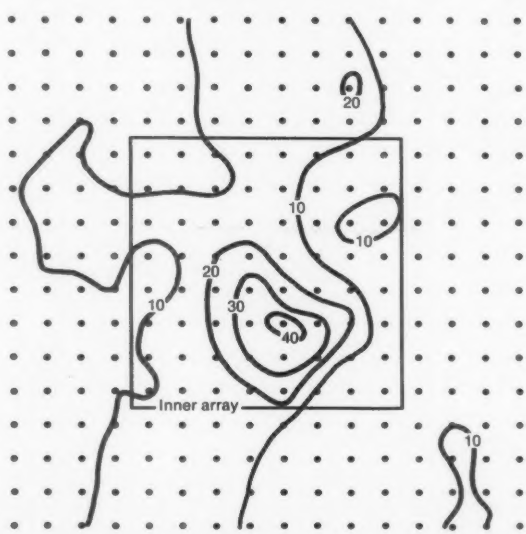

Figure 2. Original rainfall field as recorded by gauges with isohyets at 10 mm intervals.

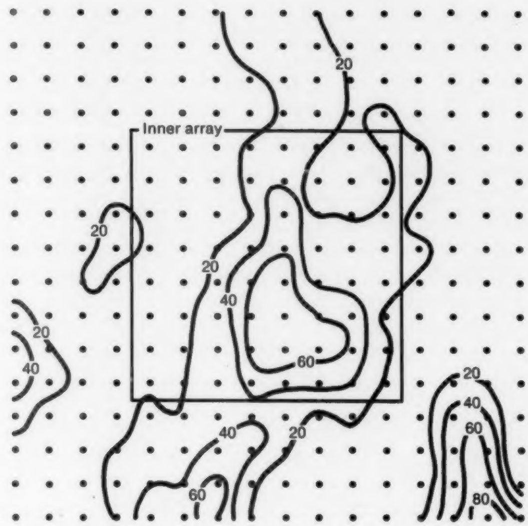

Figure 3. Original rainfall field as recorded by radar with isohyets at 20 mm intervals.

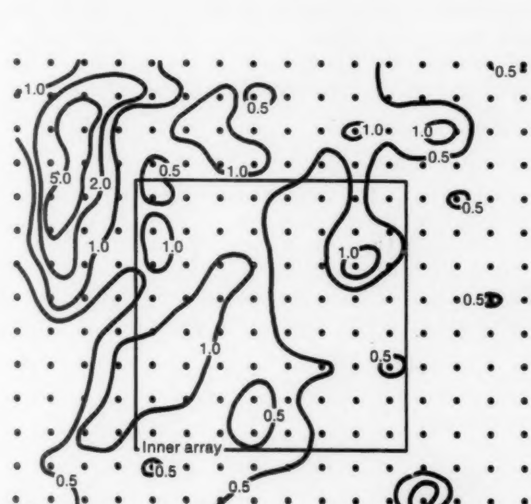

Figure 4. Field of original adjustment factors (g/r).

effect of simplifying the interpolation procedure, reducing it to taking a simple average of the corner values. The gauge-only estimate is then

$$g_e = 0.25 \sum^{i=1,4} g_i$$

compared with the co-located observed true value g_t. The square of side l and fixed orientation is moved over the array of g values so that the centre point occupies the 64 positions in the inner 8×8 array as outlined in Figs 2 and 3. This provides a sample of 64 comparisons of g_e and g_t for a square of that particular size and orientation and for that rainfall distribution.

We introduce the notation $S(q)$ to represent the standard deviation of a general variable q. Following May (1983), the mean (m) and standard deviation (s) of the sample of 64 $\log(g_e/g_t)$ values represents the bias and variability of g_e values relative to g_t such that approximately 68% of the g_e/g_t ratios are within the range $10^m \times 10^{\pm s}$. In this paper the variable component $S\{\log(g_e/g_t)\}$ is used exclusively as a measure of the error of g_e values. For brevity $S\{\log(g_e/g_t)\}$ is denoted by E_{gg} and represents the error resulting from observing with widely spaced gauges a rainfall field which would have been observed by infinitely close gauges.

The l value of the squares used to represent the network of gauges ranges in size from 7.1 to 40 km. Where squares of the same size but different orientations are used the resulting two values of E_{gg} are averaged.

Estimates from adjusted radar observations are produced in a similar way, where

$$a_e = 0.25\, r_t \sum^{i=1,4} (g_i/r_i)$$

the g_i/r_i being the adjustment factors at the corners of the square and r_t the radar value at the centre. Again the a_e values are compared with the co-located g_t values giving an E_{ag}, $S\{\log(a_e/g_t)\}$, for each sample of 64 a_e/g_t ratios for each square. E_{ag} represents the error of adjusted radar estimates. Estimates from radar-only observations (r_e) are also required in this paper giving values of E_{rr}, $S\{\log(r_e/r_t)\}$, where,

$$r_e = 0.25 \sum^{i=1,4} r_i$$

the r_i being the radar values at the corners. E_{rr} is the radar analogue of E_{gg}.

Finally the single value of E_{rg} is calculated which is the $S\{\log(r_t/g_t)\}$, where r_t and g_t are co-located, for the sample of 64 ratios from the inner array. E_{rg} represents the error of adjusted radar rainfall values and is independent of l, but since $\log(r_t/g_t) = -\log(g_t/r_t)$ and $S\{\log(r_t/g_t)\} = S\{\log(g_t/r_t)\}$, E_{rg} also represents the variability of g/r over the inner area. (To enable log ratios to be evaluated in these processes all zero values of g and r in the original arrays are replaced by 0.1 mm.)

4. Comment on the data analaysis

It should be noticed that the isopleths of g/r in Fig. 4 are fairly smooth which implies that the individual grid-point values (not shown) must be correlated with each other. As a consequence E_{rg} is only an estimate of the random variability of $\log(g/r)$ which would be difficult to define and cumbersome to determine, but nevertheless is a measure of the change in r/g or g/r with position. The same remarks apply to g_e/g_t, a_e/g_t, and r_e/r_t ratios at adjacent grid points.

It is the spatial pattern of rainfall depicted by radar observations and how well it agrees with the pattern depicted by the gauges which is important; the absolute values of radar data are not important

because biases in them with respect to gauge values are reduced by adjustment. For instance, if all the original radar values in Fig. 5 are multiplied by a constant factor then E_{rg}, E_{ag} and E_{rr} all remain unchanged and conclusions about the impact of radar data are unchanged. There is no reason why g/r values encountered in a practical adjustment process should be rejected simply because they are outside specified limits; neighbouring r values can also be much smaller or larger (in absolute units) than gauge values but can still depict the correct pattern of rainfall. Also g/r values should not necessarily be rejected because they are calculated from small values of g and/or r with the risk that rounding errors produces an increased variability in the g/r ratios; this can be regarded simply as less accurate radar data, with a larger E_{rg}.

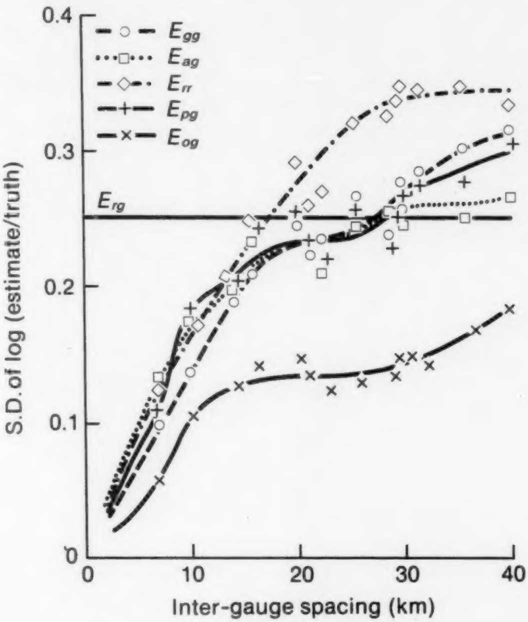

Figure 5. Variation of errors (standard deviation (S.D.) of log estimate/truth) of estimates for original rainfall data. For explanation of symbols see text.

5. Results from the original data

In Fig. 5 the values of E_{gg}, E_{ag} and E_{rr} for the original data are plotted against I with smooth curves being fitted by eye. $E_{rg}=0.25$ for the error of radar data implied by these rainfall fields and is represented by a horizontal line.

E_{gg} increases smoothly for values of I increasing from 7.1 to 40 km and can be extrapolated naturally to a zero value for $I=0$. This is consistent with more widely spaced gauges recording less accurately and infinitely close gauges recording without error at all. The magnitude of the spatial change of isohyetal gradients in Fig. 5 determines the shape and particularly the steepness of the E_{gg} versus I curve; for convenience the average gradient $\Delta E_{gg}/\Delta I$ for the I range 0 to 40 km is denoted by V_g. This is a measure

of the 'peakiness' of the field, a small V_g indicating a nearly flat field and a large V_g a very non-uniform field. For this original gauge field $V_g \approx 0.012\ \mathrm{km}^{-1}$.

E_{rr} also increases smoothly from an assumed zero value for $I = 0$ with V_r (the average gradient $\Delta E_{rr}/\Delta I) \approx 0.014\ \mathrm{km}^{-1}$.

E_{ag} also tends to zero for $I = 0$ because with decreasing distance between gauges the corner values of g/r in Fig. 1 all tend to g_t/r_t and hence a_c to g_t. E_{ag} appears to be converging to a value a little larger than E_{rg} for large values of I. This is reasonable since the wider apart the gauges are the less influence they have in comparison with radar in determining the adjusted radar field.

For these original data there is little difference between E_{gg} and E_{ag} curves in Fig. 5 although there is a critical inter-gauge spacing $(I_c) \approx 25$ km such that for $I < I_c$, $E_{ag} > E_{gg}$ and the use of radar data increases (slightly) the error of estimates, and for $I > I_c$, $E_{ag} < E_{gg}$ giving a slight decrease.

For this one example it is not possible to demonstrate how E_{ag} and E_{rr} are related to the two basic factors E_{gg} (or V_g) and E_{rg}. It is possible, though, to transform in a plausible way the original rainfall fields to simulate changes in E_{gg} and E_{rg} and the accompanying changes in E_{ag} and E_{rr}. An assumption is involved here that the behaviour of the radar observations is reasonable — for instance, if the gauge rainfall field in Fig. 2 had a peak of larger rainfalls than originally then the radar would still have observed a peak and not, say, a minimum.

The results of transforming the original data to simulate changes in E_{gg} and E_{rg} are described in the next section. This is the second part of the analysis.

6. Transformation of the data

(a) Gauge rainfall unchanged, radar data accuracy varied

To do this the original g values in the array are left unchanged, which preserves the original E_{gg} and V_g, but each original r value is replaced by $g \times (r/g)^{F_1}$, where g is co-located with r. For $F_1 = 1.0$ the r values also remain unchanged so that E_{rg} keeps its value of 0.25. From the definition of E_{rg} and the form of the transformation it follows that for any F_1, $E_{rg} = 0.25 \times F_1$ for this gauge field. Using this relationship, radar fields with specific required values of E_{rg} can easily be produced, and these fields still retain some influence of the pattern of the original radar field.

The calculation of E_{ag} and E_{rr} has been carried out as before for the range of E_{rg} values from 0.0 to 0.55. Figs 6(a), (b) and (c) show the results for $E_{rg} = 0.15$, 0.25 and 0.35 which are sufficient to demonstrate the main effects of changes in the radar data (the trend lines only of E_{gg}, E_{ag} and E_{rr} varying with I are shown for clarity). These values of E_{rg} are typical for real data.

For the most accurate radar data shown, i.e. where $E_{rg} = 0.15$, the curves of E_{rr} and E_{gg} nearly coincide (and V_r tends to V_g) because the simulated radar field is very similar to the gauge field. As the radar data degrade in accuracy the radar field is an increasingly inaccurate image of the gauge field and the E_{rr} curve steepens. As suggested previously, for large values of I, E_{ag} tends to a value determined by E_{rg}; as a consequence, since the E_{gg} curve is fixed, for more accurate radar data $E_{ag} < E_{gg}$ over the whole range of I but for less accurate radar data $E_{ag} > E_{gg}$. For the less accurate radar data it is the E_{rr} and E_{ag} curves which converge.

(b) Radar data error unchanged, gauge rainfall field varied

This requires two transformations of the arrays of data. Firstly, each original g is replaced by $\bar{g} \times (g/\bar{g})^{F_2}$ where $\bar{g}$ is a constant, chosen to be the average g over the whole array. By itself this would change the g values, E_{gg} and V_g, as required but also the r/g ratios, so to retrieve the original $E_{rg} = 0.25$ the original r values are also replaced by $r \times (g/\bar{g})^{(F_2 - 1.0)}$. For $F_2 = 1.0$ the original r and g values are

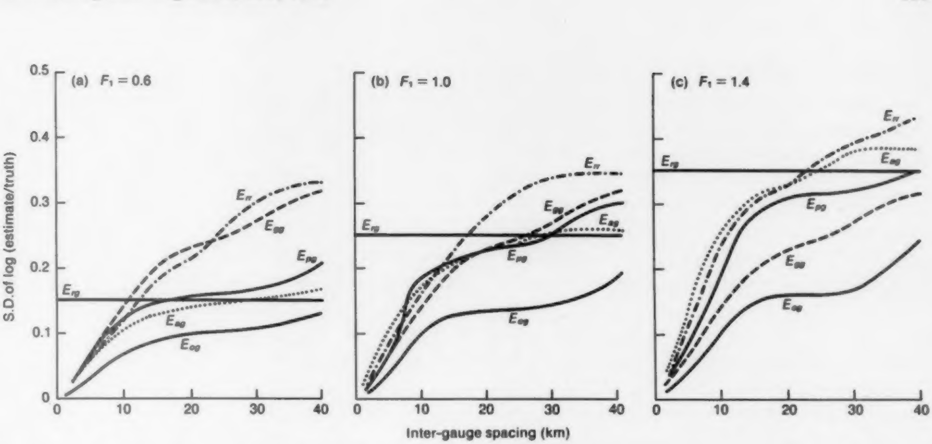

Figure 6. Variation of errors (standard deviation (S.D.) of log estimate/truth) of estimates when original gauge rainfall remains unchanged but radar field is varied to simulate changes of rainfall data accuracy.

unchanged; as F_2 tends to zero the g values all tend to $\bar{g}$ and the rainfall field pattern flattens, but for $F_2 > 1.0$ the gauge field is more non-uniform than originally.

The calculation of the errors has been made as before for simulated fields for a range of F_2 from 0.0 to 3.0. Figs 7(a), (b) and (c) show the results for $F_2 = 0.5$, 1.0 and 1.5 which give a practical range of values of V_g from 0.006 to 0.018 km^{-1}.

Again irrespective of the flatness of the rainfall field the E_{rg} strongly determines the variation of E_{ag} with l. Since the E_{ag} curve is nearly fixed the change in V_g results in $E_{gg} < E_{ag}$ for all gauge spacings for the flatter field and $E_{gg} > E_{ag}$ for the more variable field. As the rainfall field becomes less flat the E_{rr} curve departs from the E_{ag} curve and approaches the E_{gg} curve.

Figs 6 and 7 show how estimate errors change with different gauge rainfall fields and errors of radar data. In the next section the implications of these results are discussed.

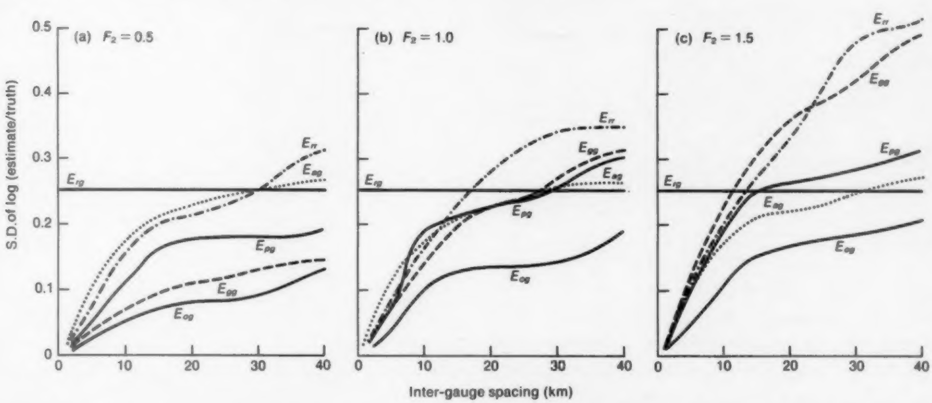

Figure 7. Variation of errors (standard deviation (S.D.) of log estimate/truth) of estimates for simulated changes of uniformity of rainfall fields as recorded by gauges but keeping the original g/r field unchanged.

7. Discussion of results from changing E_{rg} and V_g

(i) Figs 6(a) and 7(c) are similar in the relative positions of the E_{gg}, E_{ag} and E_{rr} curves which differ only in the vertical scale, and the same is true for Figs 6(c) and 7(a). This suggests that an important factor is the relative magnitude of the error of radar data and the variability of the gauge field.

(ii) For a particular rainfall field, accuracy of radar observations, and inter-gauge spacing the use of radar data to estimate rainfall can be regarded as beneficial if $E_{ag} < E_{gg}$ and non-beneficial if $E_{ag} > E_{gg}$. The concept of a critical inter-gauge spacing I_c as in Fig. 5 is not very relevant in practice. For a particular E_{rg} a small change in V_g (or vice versa) appears to produce a large change in I_c, as demonstrated by the entries in Tables I(a) and (b), and when $I_c \approx 20$ km E_{gg} and E_{ag} are nearly identical

Table I. *Transformation of original data to simulate changes in E_{gg} and E_{rg}*

(a) Gauge rainfall field unchanged, radar data error varying

F_1	E_{rg}	V_g (km^{-1})	V_r (km^{-1})	Gauge spacing at which: $E_{rr} \approx E_{rg}$ (I_a) (km)	$E_{ag} \approx E_{rg}$ (I_b) (km)	$E_{gg} \approx E_{ag}$ (I_c) (km)	Effect of radar data: beneficial (b) or non-beneficial (n)	Test of choice methods: Optimum: % number of g_c N_g	Practical: % correct choices N_{pc}	Practical: mean ratio E_{pg}/E_{cg}	Comments
0.0	0.00	0.012	0.012	0	—	—	b	0	100	1.0	For $F_1 = 0.0$, the
0.2	0.05	0.012	0.012	4	33	0	b	14	82	1.2	r/g field is flat,
0.4	0.10	0.012	0.012	8	28	0	b	24	63	1.5	radar and gauge
0.6	0.15	0.012	0.012	13	28	0	b	35	57	1.6	fields are not.
1.0	0.25	0.012	0.014	18	27	≈ 25	neither	50	50	1.8	As F_1 increases,
1.4	0.35	0.012	0.016	23	25	> 40	n	63	51	1.9	the radar data
1.8	0.45	0.012	0.019	26	23	$\gg 40$?	n	70	54	1.9	gradually
2.2	0.55	0.012	0.026	30	20	$\gg 40$?	n	76	56	1.9	deteriorate

(b) Radar data error unchanged, gauge rainfall field varying

F_2	E_{rg}	V_g	V_r	I_a	I_b	I_c	Effect	N_g	N_{pc}	E_{pg}/E_{cg}	Comments
0.0	0.25	0.000	0.012	15	30	—	n	100	61	—	For $F_2 = 0.0$, gauge
0.1	0.25	0.001	0.012	22	30	$\gg 40$?	n	87	59	5.4	rainfall field is
0.5	0.25	0.006	0.012	30	30	$\gg 40$	n	68	50	2.0	flat, radar and
0.8	0.25	0.009	0.012	22	28	> 40	n	58	50	1.9	r/g fields are
1.0	0.25	0.012	0.014	18	27	≈ 25	neither	50	50	1.8	not. As F_2
1.2	0.25	0.015	0.016	15	28	0	b	44	52	1.7	increases, the gauge
1.5	0.25	0.018	0.017	13	29	0	b	36	57	1.6	field becomes
2.0	0.25	0.025	0.025	9	28	0	b	32	64	1.5	more variable
3.0	0.25	0.039	0.039	6	28	0	b	18	77	1.3	

with little benefit or harm resulting anyway. The more interesting conditions are when $I_c \approx 0$ or > 40 km and V_r and V_g are very different as in Figs 6(c) and 7(a) and Table I.

(iii) It is convenient to regard radar data which result in $E_{ag} < E_{gg}$ as being 'accurate', and 'inaccurate' if $E_{ag} > E_{gg}$. However, a particular value of E_{rg} cannot be accurate or inaccurate on an absolute scale because the effect of using radar data depends on the field (V_g) being observed and, to a lesser extent, the gauge spacing. For instance, in Fig. 7(a) for $E_{rg} = 0.25$ the radar data are inaccurate because a uniform

rainfall field is being observed and gauge estimates have less error than adjusted radar estimates (non-beneficial use) whereas in Fig. 6(c) the same quality radar observations of a much more variable field lead to poorer gauge estimates than adjusted radar ones (beneficial use). Cases of beneficial and non-beneficial use of radar data are also indicated in Table I.

(iv) There is no automatic beneficial trade-off between radar observations and numbers of gauges to maintain a specified error of estimates — beneficial in this case meaning that l can be increased when radar data are used. For instance, in Fig. 7(c) an error of estimates equal to 0.25 can be achieved by gauges only with $l = 12$ km but l can be increased to 30 km (a reduction in gauge numbers per unit area by a factor of 0.16) when the gauges are used to adjust radar observations and so there is a positive trade-off. From Fig. 6(c) for the same error, $l = 26$ km for gauge-only estimates but is 10 km for adjusted radar estimates and there is now a negative trade-off. In the first case the radar data are capable of contributing useful information to the radar and gauge combined field so reducing the need for gauges; in the second case the radar contributes misleading information and so more gauges are needed to compensate. Positive trade-offs are associated with the beneficial use of radar data and negative trade-offs with non-beneficial use.

(v) There appears to be a strong association between the distance (l_a) at which $E_{rg} \approx E_{rr}$ and whether the radar data are beneficial or non-beneficial. From Table I it can be seen that beneficial radar data result in values of l_a less than about 20 km and non-beneficial data with l_a more than about 20 km. It is thought that this change-over value of l_a is not absolute but is characteristic only of the particular rainfall pattern used here.

(vi) The approximately constant distance (l_b) at which $E_{rg} \approx E_{ag}$ (from Table I) is associated with the strong control by E_{rg} of the limiting value of E_{ag} for large values of l. For very sparse gauges then (a practical circumstance) the error of adjusted radar estimates is determined almost completely by the error of radar data and not by the variability of what is being observed.

(vii) For perfect radar data, i.e. $F_1 = 0.0$, the 5 km grid of radar observations behaves like a 5 km network of gauges. If the real gauges are distributed uniformly with a spacing of l km then the combined network of observations would have an average spacing of

$$\left(\frac{1}{5^2} + \frac{1}{l^2}\right)^{-\frac{1}{2}} \text{ km}$$

giving an error of estimates which can be read off the E_{gg} versus l curve for the rainfall field being observed.

(viii) With so much variety encountered in the variability of rainfall fields and the accuracy of radar observations it is impracticable to specify gauge spacings to cater for all circumstances. Irrespective of whether the radar data are used or not it is advisable to use as many gauge observations as possible since all the figures show that E_{gg} and E_{ag} both decrease continuously with l.

In summary, radar data can be beneficial or non-beneficial so that if used indiscriminately and inappropriately there is a risk of an increase of errors of rainfall estimates.

The next section deals with the possibility that for the rainfall fields, radar data errors and sparse gauge spacings met in practice, an objective decision can be made whether or not to use radar data.

8. Development of a practical method of deciding when to use radar data

In simulation there is no difficulty in deciding when to use radar data or not because g_t is available for direct comparison with a_e and g_e. In practice g_t is not available so the problem is to develop a method of deciding between g_e and a_e without knowing g_t exactly. This is the third part of the analysis.

Before going on to consider how to make this choice it is necessary to establish the desirable features of a practical method.

(i) The simulations suggest that the beneficial or non-beneficial use of radar data depends on the rainfall field variability and the accuracy of radar observations such that accurate observations and variable fields favour the use of adjusted radar estimates, and inaccurate observations and flat fields favour the use of gauge-only estimates. The method should contain elements which represent the competition between these two factors.

(ii) The rainfall field variability and radar data accuracy vary continuously from one grid point to the next so the choice of using g_e or a_e should be made independently at each grid point. It should not be inevitable that the choice at adjacent grid points is the same since in practice this could lead to hard-edged areas containing either all g_e or all a_e estimates. This may arise by chance but should not arise by design. This suggests that the method must involve 'local' (to the grid point) estimates of field variability and radar data accuracy.

(iii) No method of choosing g_e or a_e can be 100% correct since g_t is not known; however r_t is known and can be used but is an imperfect estimate of g_t. The choice between g_e and a_e must inevitably depend on probability considerations.

(iv) The method must be effective in preventing as far as possible the obviously incorrect choice of g_e or a_e being made.

(v) It would be useful if the method could be integrated into the operational procedures described in section 1 used for obtaining g_e and a_e in practice.

The practical circumstances are as pictured in Fig. 1. The accuracy of radar observations at X can be estimated only from the sparse gauge measurements in the vicinity, and the variability of the gauge rainfall field judged from the inaccurate radar observations.

To test the effectiveness of a method of choosing, a rule is required to determine which is the better of g_e and a_e as an estimate of g_t when g_t is known. The rule follows naturally from the use of $S\{\log(g_e/g_t)\}$ and $S\{\log(a_e/g_t)\}$ to measure errors in the samples of g_e and a_e values — being that g_e is the better estimate if $|\log(g_e/g_t)| < |\log(a_e/g_t)|$, otherwise a_e should be chosen. The absolute values are used, there being no concern as to whether g_e and a_e are greater or smaller than g_t.

9. The optimum solution

At this point it is useful to derive by simulation the errors to be expected for the hypothetical situation in which the correct choice of g_e and a_e can always be made — the optimum solution. Using the data arrays described previously, for each sample of 64 values the $S\{\log(o_e/g_t)\}$ (denoted by E_{og}) can be calculated where o_e is the better of g_e and a_e determined by the rule above. In addition, from each sample the number of occasions out of 64 that g_e is the better estimate (N_g) is counted and expressed as a percentage; a_e is then the better estimate on $(100 - N_g)$ % of occasions. The value of simulated estimates of E_{og}, for the optimum solution, is that they can act as a standard for the performance of practical methods of choosing g_e and a_e.

By definition, for a particular rainfall field, E_{rg}, and value of I, E_{og} must always be less than both E_{gg} and E_{ag} which can be seen from Figs 6 and 7 where E_{og} is plotted against I. N_g appears to be nearly independent of I for a particular gauge and radar rainfall field and so the mean values of N_g averaged over all I values in the range 7.1 to 40 km are given in Table I.

For the original gauge data and $E_{rg} =$ 0.0 the r/g field is flat, giving error-free adjusted radar estimates, but the g field is not flat resulting in erroneous gauge-only estimates so that $N_g = 0\%$. As E_{rg} increases the radar estimates become progressively less accurate and some values of g_e are chosen in preference to a_e, so N_g increases. In contrast, for a flat rainfall field and a non-flat r/g field, g_e is always

chosen so $N_g = 100\%$, but as the rainfall field becomes variable values of a_e start to be chosen and N_g decreases. These values of N_g are consistent with E_{gg} and E_{ag} in Figs 6(a) and 7(c) — when $E_{gg} > E_{ag}$ (i.e. beneficial radar data), N_g is $< 50\%$ and vice versa. For the original data $N_g \approx 50\%$ so that neither g_e nor a_e is strongly preferred. This is consistent with the E_{gg} and E_{ag} curves being nearly coincident in Fig. 5.

10. A practical solution

Referring to the practical circumstances in Fig. 1, an estimate of $S\{\log(r/g)\}$ at X can be found from the surrounding gauges selected in the operational process to adjust the radar value at X. This estimate is inevitably based on only a few values of r/g but it is the best local area estimate that can be made of the error of radar data. The gauge observations can be used to estimate g_e at X but there is no observed g_t for comparison. An alternative is to calculate r_e at X from the radar values at the gauge locations for comparison with r_t at X, which is available. The radar equivalent of g_e/g_t, r_e/r_t, is a measure of the flatness of the rainfall field in the same local area surrounding X as that for $S\{\log(r/g)\}$. Because of the inaccuracy of radar data r_e/r_t is a less reliable index of flatness than g_e/g_t which decreases the precision of the test.

The practical test then becomes — choose g_e if $|\log(r_e/r_t)| < S\{\log(r/g)\}$, otherwise choose a_e.

As before, the results to be expected from this method of choosing g_e or a_e can be simulated. From Fig. 1, the $S\{\log(r/g)\}$ estimate is derived from the four corner values of r/g and the r_i values at the corners give r_e at the centre to form the $\log(r_e/r_t)$ estimate. The test is applied for each particular size and orientation of the square, at the 64 positions of the centre point, and the chosen a_e or g_e (denoted by p_e) is used to calculate $S\{\log(p_e/g_t)\}$ (denoted by E_{pg}). A count is also made of the number of occasions out of 64 on which the test chooses the better estimate correctly and this is expressed as a percentage (N_{pc}). It is found that for a particular E_{rg} and rainfall field, N_{pc} is nearly independent of l and so only mean values of N_{pc} over the l range 7.1 to 40 km are quoted. The results of simulating the operation of this practical choice method are given in Table I.

From Table I(a) it can be seen that with the original gauge rainfall field and a uniform r/g field (i.e. $E_{rg} = 0.0$) the correct choice of estimate (a_e) is always made and as a consequence the accuracy of estimates chosen reaches the limit E_{og} set by the optimum choice method. As the radar data deteriorate in accuracy the success rate of correct choice falls to a value of 50% — by coincidence for the original data. At first this appears to be a poor success rate, being no better than the random choice rate, but it is consistent with the E_{gg} and E_{ag} curves in Fig. 5 which show that there is little to choose between g_e and a_e on average in these conditions. Even if the method preferred one kind of estimate to the total exclusion of the other the success rate would still be 50% because one half of the correct estimates are g_e ($N_g = 50\%$ in Table I) and one half are a_e. However, the penalty for being unable to choose the correct estimate on no more than 50% of occasions is that $E_{pg} = 1.8 \times E_{og}$. As the radar data deteriorate even further the success rate increases again with g_e now more often being the preferred value but E_{pg}/E_{og} continues to increase slightly. In contrast, from Table I(b) it can be seen that for the original radar data error but varying rainfall field a 61% success rate of correct choice is obtained for a flat gauge field with g_e being preferred more often. The ratio E_{pg}/E_{og} loses its significance under this condition because both E_{pg} and E_{og} are close to zero. As the field becomes more variable the success rate reaches a minimum of 50% and then increases again with a_e now being preferred more often but the ratio E_{pg}/E_{og} continues to improve, apparently to a limiting value of 1.0.

The significant features of Table I are that the choice method works well in terms of a favourable N_{pc} (i.e. $> 50\%$) in circumstances when one or other of the estimates is clearly better, and particularly well with good radar data. When radar data are beneficial the efficiency ratio E_{pg}/E_{og} is less than 1.8.

11. Some practical considerations

The advantages of simulation in this work are that conditions can be altered and results for perhaps unrealistic circumstances can be produced, these being useful for revealing the underlying processes. However, simulation as used here only results in the calculation of the statistics of errors of fields and not actual fields of g_e, a_e, o_e and p_e. The next phase of this work is to investigate whether these results are reproduced, even approximately, with real fields.

Retrospectively, procedures described in the introduction can be used to derive grid-point value fields of g_t from the full gauge network, g_e from a sparse gauge network and a_e from radar data adjusted by the sparse gauges. Four further fields can then be derived — the optimum choice and an accompanying field indicating whether g_e or a_e is the optimum choice at each point, and the practical choice of g_e or a_e and its field of indicators of correct or incorrect choice. It would be expected that the following features would be exhibited by these fields:

(i) With decreasing distance from a gauge in the sparse network the probability that g_e is the optimum estimate should increase. This should result in a concentration of g_e choices around the gauge, possibly to the total exclusion of a_e choices.

(ii) With increasing distance from the gauges the probability that a_e is the preferred estimate should increase. It is possible, though, that for a very non-uniform r/g field, a very flat gauge field or close gauges in the sparse network, a_e values are still not the better even at the remotest points between gauges.

(iii) If the practical choice method is used, then close to the gauges there should be a concentration of correct choices (of g_e). More remotely from the gauges incorrect choices should occur but if the radar data error is small then the relative number of incorrect choices should also be small and the number of correct choices (now a_e) should be large.

A point of interest concerns the appearance of hybrid rainfall fields which are represented by grid-point values of interspersed g_e and a_e estimates. No restriction can be imposed that g_e or a_e should be smaller, or larger, than g_t because g_t is not known. At one point an estimate which is larger than g_t can be chosen while at the neighbouring point an estimate which is smaller than g_t can be chosen. This may lead to the introduction of spurious features into the practical choice field even though there is a bona fide better estimate at each individual point. Comparisons of p_e and g_t fields should show whether this is likely to be a problem in practice.

The errors of radar data depend on a variety of factors including the distance from the radar installation, the types of rainfall occurring during the duration involved and, therefore, on the duration itself, topography, and the sampling interval used to derive the radar rainfalls. The variability of rainfall fields would depend mainly on rainfall type and duration. It would be possible to investigate accuracy of radar data and variability of rainfall for durations of a day or longer with existing data but it would be difficult for sub-daily durations because of a lack of dense recorder networks to provide g_t fields.

In principle these methods can also be applied to areas as well as points. It is likely that for areas both the errors of radar data and the variability of rainfall fields are smaller than for points because of the reduction due to areal averaging. Figs 6(a) and 7(c) indicate that if the data error and field variability reduce in the same proportion then the error curves retain their relative pattern and E_{ag}, E_{og} and E_{pg} also reduce. This is a matter of real practical interest because there is a requirement to develop a method to decide when radar observations are beneficial in estimating daily rainfalls averaged over 40×40 km squares, with sparse gauges and no truth field, for application in the Meteorological Office Rainfall and Evaporation Calculation System. A possible method is to produce the p_e field as described above and average the 64 p_e values to form the 40×40 km square values required; this keeps the decision of whether to use radar data at the 5 km spacing level and so changes in the conditions within each large square can be accounted for.

12. Conclusions

Fields of rainfall amount for a specified duration can be derived by interpolation within sparse gauge observations (g_e) or from dense radar observations adjusted by the gauge observations (a_e). Over an area the gauge-only field can be a better estimate of the true gauge field than the adjusted radar field or vice versa; it depends on the relationship between the accuracy of radar observations (compared with co-located gauge ones) and the variability of the rainfall field being observed. At specific locations it is not possible to determine with 100% success which of g_e and a_e is the better estimate but a method has been developed which embodies the two competing factors above and which gives a success rate of choice better than the 50% from chance.

Without such a choice being made it is possible for radar data, used indiscriminately, to be non-beneficial.

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An occasion of high absolute humidity in England: 1 July 1968

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Summary

Occasions of high absolute humidity are worthy of study in view of their importance for the proper functioning of air-conditioning plant at large computer installations. On 1 July 1968, dew-points reached at least 18 °C for several hours over almost the whole of southern England and at least 20 °C over smaller, though still considerable, areas. This was the most extreme occasion of widespread high humidity during the period 1957–80.

Bilham (1938), in his book *The climate of the British Isles*, included a section entitled 'Extremes of absolute humidity' which was in part based on earlier work by Dight (1934). Dight had prepared a table of all occasions from 1900 to 1933 when temperature exceeded 85 °F at Kew Observatory, together with the associated humidity data, from which Bilham extracted occasions showing 'a notably high value of the absolute humidity'. The criterion used by Bilham, to judge by the values he quotes, was a vapour

pressure of at least 19.9 mb, i.e. a dew-point of at least 17.4 °C (63.3 °F); the highest value at Kew was 23.9 mb (dew-point 20.4 °C). Such occasions of high absolute humidity have assumed a new interest in recent years with the development of elaborate computer installations, the proper functioning of which is crucially dependent on the proper environmental conditions of temperature and humidity; if the dew-point in the ambient air is too high for the air-conditioning system to cope with, the computers will have to be closed down, an important consideration for real-time systems or those working to a tight schedule, such as weather forecasting. Knowledge of the most unfavourable conditions possible is therefore important.

Climatological Memorandum No. 103 (Meteorological Office 1976) indicates that over the whole of England (except the extreme north) and South Wales the maximum dew-point during the years 1961–70 equalled or exceeded 19.0 °C (equivalent to a vapour pressure of 22.0 mb). Use was therefore made of a series of climatological data tapes of hourly values, mainly for the years 1957–80, available in the Special Investigations Branch, to search for occasions when vapour pressure ⩾21.5 mb (or dew-point ⩾18.6 °C). The stations surveyed were Boscombe Down (1957–80), Dungeness (1957–79), Exeter (1957–80), Filton (1957–79), Gloucester (1960–80), London/Heathrow Airport (1957–80), Waddington (1957–80) and Watnall (1957–80) for the months June to September. Of these eight stations, 1 July 1968 came out as top of the list at six and was also selected at another station leaving only one (Dungeness) where it failed to qualify. Very high absolute humidities were therefore exceptionally widespread over southern England on 1 July 1968 and the occasion was thought to merit more detailed examination.

The occasion, 1 July 1968, has been studied in detail by Stevenson (1969) because on that day there were extensive outbreaks of thundery rain which deposited large amounts of red Saharan dust over a wide area. Stevenson's paper analyses the synoptic situation and presents detailed isentropic analyses. She does not, however, comment on the high absolute humidities, and these are shown in Figs 1(a), (b) and (c).

Of individual stations, Watnall is remarkable as having recorded at 12 GMT a dry-bulb temperature of 29.9 °C and a wet-bulb temperature of 24.9 °C, yielding a dew-point of 22.7 °C. This value of dew-point compares with values of 21.4, 21.2 and 20.7 °C at 10, 11 and 13 GMT respectively and might possibly, therefore, be due to an error in reading the wet bulb, although at an official station this is most unlikely. (The evidence of the hygrogram is inconclusive.)

The winds over England were relatively light, though by no means calm. The reported dew-points might therefore have been too high by a degree or so. Regrettably, aspirated psychrometer records were not available at Kew or any other station known to the author. Nevertheless, we may draw the conclusion that on one occasion in the period 1957–80 (24 years) dew-points over almost the whole of southern England reached values of at least 18 °C for several hours and of at least 20 °C over smaller though still considerable areas. Whether this occasion qualifies as the most notable this century for widespread and persistant high absolute humidity cannot be judged without painstaking investigation of the records from before the era of the machinable data set; almost certainly, however, it must be near the top of the list, and forms a useful benchmark for assessing similar occasions in the future.

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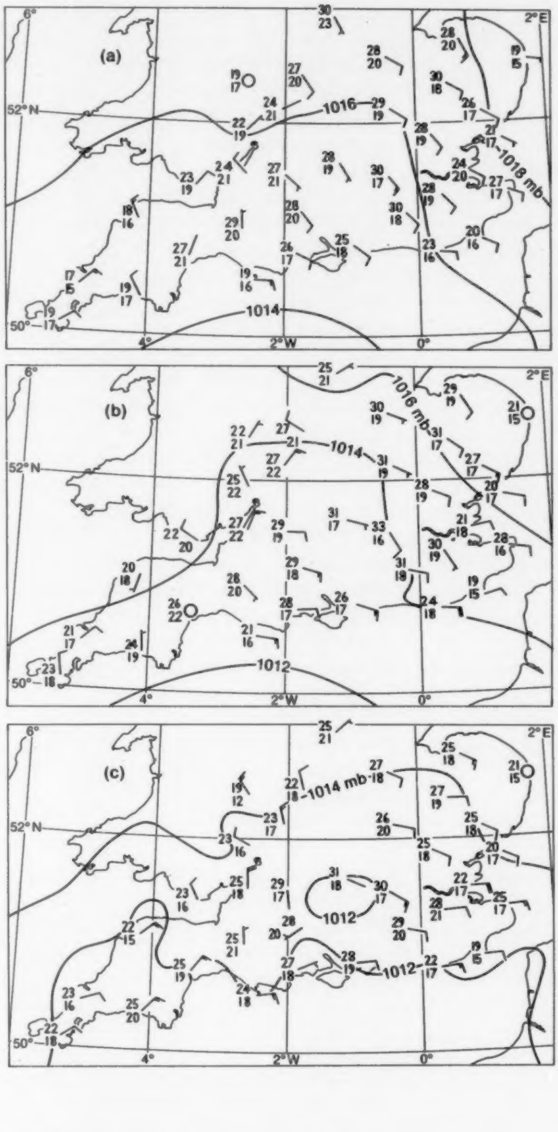

Figure 1. Wind direction and speed (one long feather = 10 kn), and dry-bulb and dew-point temperatures over southern England on 1 July 1968 at (a) 12 GMT (b) 15 GMT and (c) 18 GMT. Isobars are shown at 2 mb intervals.

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Royal Meteorological Society

The title of the meeting of the Society held on 18 December 1985 was 'Climatic impact of nuclear war', a topic now often referred to as 'nuclear winter'. The meeting, held in the Department of Mechanical Engineering at Imperial College, London, attracted a large audience; the President of the Society, Mr A. Gilchrist, was in the Chair. After a few brief remarks the President called on Dr A. Slingo of the Meteorological Office to take general charge of the meeting and introduce the principal speakers.

Dr Slingo began by giving a brief historical sketch of a subject which, as he said, did not exist five years ago. During this time, a single paper published in 1982 in a Swedish environmental journal had led to a substantial international research effort into the so-called nuclear winter. As with previous environmental issues (for example, 'acid rain', the effects of supersonic transport, chlorofluoromethanes, and carbon dioxide and other trace gases) the subject had attracted wide interest from non-meteorological scientists, environmentalists, politicians and the general public at a time when the subject was still growing rapidly and new research was being undertaken. It was appropriate, therefore, that the Royal Meteorological Society should take the opportunity to review the scientific arguments in the nuclear winter hypothesis, to discover where (if anywhere) there was consensus, where there were uncertainties and disagreements, and if possible to identify where new work was needed. Dr Slingo briefly sketched the standard scenario for the nuclear winter as follows:

1. Extensive nuclear exchange (about 5000 Mt).
2. Immediate effects — blast, radiation, oxides of nitrogen, thermal pulse.
3. Thermal pulse ignites material over wide area — city and forest fires.
4. Smoke palls contain large quantities of carbon aerosol of size $\leq 1\ \mu$m. Some removed by precipitation — black rain.
5. Remaining smoke absorbs sunlight very effectively — atmosphere warms.
6. Surface insolation falls — surface cools.
7. Smoke plumes rise and merge.
8. Heated atmosphere above cooled surface. Convection suppressed so smoke resists further scavenging.
9. Changes induced in general circulation.

The typical result is that surface temperatures will fall by about 20–30 °C in summer and remain low for several weeks.

Dr R. Harrison, of the University of Essex, then described the relevant properties of different aerosols. There were three major sources: industrial fires, forest fires, and dust (as distinct from aerosols generated by combustion) raised by winds or produced by volatilization. Important properties of aerosols are their size distributions, chemical composition, rates of coagulation, rates of loss to various sinks, and optical characteristics. (Examples of 'sink' processes are sedimentation, scavenging, and diffusion.) Dr Harrison showed how different ways of expressing size distribution, for example by number, surface area, or mass per unit volume, led to very different formulae. In the discussion following Dr Harrison's paper, Professor Percival of Queen Mary College, London said that the *shapes* of the aerosol particles had a marked effect on several of the properties described, and more work was needed on this.

Dr K.P. Shine (Department of Atmospheric Physics, University of Oxford) gave an account of the relevant radiation physics. He showed how relatively simple models could demonstrate the sorts of effects that could occur when a large mass of particulate absorbing matter was injected into the atmosphere. As more and more 'soot' is added, the balance between radiative and convective

equilibrium leads to a progressive lowering of the tropopause until it reaches the earth's surface, and the effect on surface temperature moves from a possible slight warming to a strong cooling. However, while discussing a slide showing various predicted values, Dr Shine warned his audience that a mathematical model of the type he had described was little more than an educational toy which illustrated certain physical processes that *might* occur on the basis of sweeping assumptions and numerous approximations; results from such a model were open to very serious misinterpretation. Dr Shine concluded by describing some of the important characteristics of an aerosol that determine its effect on radiation, how complicated they were, and how uncertain was the derivation of bulk parameters for use in any radiative–convective model simple enough to be handled mathematically.

From the floor, Professor Scorer remarked on the apparent unreality of the current discussions. Why should something like a classic local smog situation persist for a long period over a huge area subject to normal atmospheric processes on the synoptic scale? Dr Slingo said that later speakers would be discussing this very point.

Mr D.E. Parker (Meteorological Office) described work he had carried out on the effects of major volcanic eruptions over the past 100 years. After remarking that volcanic eruptions were by no means good analogues for a nuclear war, he showed that their effect on surface temperatures was too small to be disentangled from the natural variability always present.

Dr J.F.B. Mitchell (Meteorological Office) described some modelling experiments that had been carried out in the Meteorological Office. Because of the speculation that smoke from fires following an extensive nuclear war could lead to changes in climate, several sensitivity studies had been carried out using existing three-dimensional atmospheric general circulation models. Preliminary experiments indicated that a full-scale nuclear war would produce a reduction of surface temperature over the northern mid-latitude continents of about 25 °C in summer with substantially smaller reductions at other times of the year. In a later study, in which the advection of smoke and scavenging by precipitation were parametrized, the surface cooling was less severe. Dr Mitchell emphasized that these results were crucially dependent on enough smoke being released into the atmosphere and on the assumption that the smoke is uniformly mixed in the troposphere on a continental scale. As at present these assumptions are largely a matter of speculation, there was little point in carrying out more elaborate experiments using general circulation models until the initial conditions could be specified with more confidence. Dr Mitchell also pointed out that the general circulation models now in use had been developed to take account of perturbations of a size occurring naturally; the perturbation introduced by the type of smoke cloud assumed to be produced by a nuclear winter was so very much larger, that the physical reality of the model results was questionable.

Dr P.M. Kelly (University of East Anglia) discussed the application of the results of various model experiments to the United Kingdom. It seemed that effects on temperature were likely to be relatively small in winter, but could be large and very serious in summer. There was some discussion from the floor, in which Dr A.F. Tuck and Dr P. Jonas (both of the Meteorological Office) took part, on the influence of the assumptions made involving wash-out of smoke.

Mr B.W. Golding (Meteorological Office) discussed the possible effects of mesoscale perturbations on the nuclear winter hypothesis. Calculations of possible widespread and long-term atmospheric effects from a massive nuclear exchange had so far been carried out using models with rather coarse grids, equivalent to about 5° of latitude, suitable for normal synoptic-scale forecasting. This meant that effects due to the initially patchy nature of the smoke could not be modelled properly. He described recent work using a mesoscale model extending over the area of the British Isles which had a horizontal grid length of 15 km and 16 levels in the vertical. The model was modified to include advection of smoke and also a parametrization of short-wave radiative heating by smoke. A smoke source was inserted in a column of radius 75 km near Manchester, and the initial conditions were for a real day of anticylconic

weather in summer. The results showed that a direct circulation set up by heating of the smoke could lead to cloud formation near its top. This might have important consequences for the subsequent evolution of the smoke pall. Further work was needed to determine the sensitivity of the model to the approximations made and to the initial conditions. More detailed treatment of the source region was desirable and so was the inclusion of the interaction between winter and smoke.

Professor Scorer asked why a simpler case had not been studied, such as a circular island with symmetrical orography; this might have revealed all that was significant in the results. Mr Golding replied that a suitable model already designed for mesoscale forecasting over the United Kingdom was available, and use was made of it.

Dr A.F. Tuck (Meteorological Office) began his talk on the effects of nuclear war on ozone by saying, echoing Robert Boyle, that his discourse might well have been entitiled 'A sceptical chymist looks at nuclear winter'. He pointed out that the direct chemical products of nuclear fire-balls included large quantities of NO_2, a gas which absorbs strongly in the near ultraviolet and visible spectrum. The effect of this on the transmission of solar radiation should be considered, since it would affect the amount of radiation which could be absorbed in any soot clouds which might subsequently develop beneath. NO_2 and HNO_3 also have infra-red spectral features in the 'atmospheric window' region (7–14 μm) and so do other gases which are products of complete or partial combustion of organic and fossil fuel material; SO_2, C_2H_6, C_2H_4, and any molecule containing a C–O vibration for example. Very crude order-of-magnitude estimates suggest that the 'greenhouse' effect from these gases (which will be present in the smoke) should be studied with better radiative transfer calculations than those hitherto employed. To give an accurate quantitative assessment of all the chemical reactions that might take place following the incineration of a large industrial city was a matter of extreme difficulty.

Professor Sir Frederick Warner, FRS (Scientific Committee on Problems of the Environment (SCOPE) and the University of Essex) who is Chairman of the Steering Committee of the SCOPE project on Environmental consequences of NUclear WAR (ENUWAR), gave a brisk and professional presentation of the main conclusions contained in the ENUWAR report which had been presented in September 1985 to the SCOPE General Assembly in Washington DC, USA. These conclusions were based on the results of a variety of modelling experiments and much other evidence. It seemed that the indirect environmental effects of a nuclear war, though perhaps not so extreme as early studies had predicted, would nevertheless be no less serious for non-combatant than for combatant nations. Sir Frederick did not, however, discuss the implications for these conclusions of the views put forward at the current meeting.

Dr Slingo, in drawing the meeting to a close and in response to various questions from the floor, emphasized his misgivings that excessively sweeping conclusions were being drawn from the results of model experiments by people who did not fully understand, and were not in touch with, the actual work. Experience in the Meteorological Office had shown that large-amplitude atmospheric waves were excited by the dust cloud perturbation, and the origins and reality of these waves were still not properly understood.

Notes and news

Summer school at Dundee University

A postgraduate summer school on *Remote Sensing Applications in Meteorology and Climatology* will be held at the University of Dundee, from 17 August to 6 September 1986. The summer school is intended for meteorologists, postgraduate students, fresh postdoctoral research workers and other workers in the field and will concentrate on recent developments and active areas of research work. The topics to be covered in the school are expected to include the following: Introduction to atmospheric physics and remote sensing; Data acquisition; Pattern recognition and image processing; Satellite data as input to numerical weather prediction models; Satellite data and hurricane prediction; Use of radar and satellite data for estimation of precipitation; Observations of the middle atmosphere from satellites; Studies of synoptic and mesoscale systems from satellites; Cinematographic methods for the study of atmospheric motions; Multispectral classification of clouds, fog and haze; Remote sensing of sea-surface winds; Atmospheric moisture and oceanic latent heat flux; Climatological data set and climatological modelling; and Earth–atmosphere radiation budget and climatology from satellites.

In addition to the formal lecture programme, a number of less formal seminars will be held and there will be practical exercises based on photographic imagery, video, film and slide material, and digital printouts organized in the laboratory. Practical exercises to illustrate to participants the important digital image processing operations are also expected to be available.

Some bursaries may be available to assist students to attend.

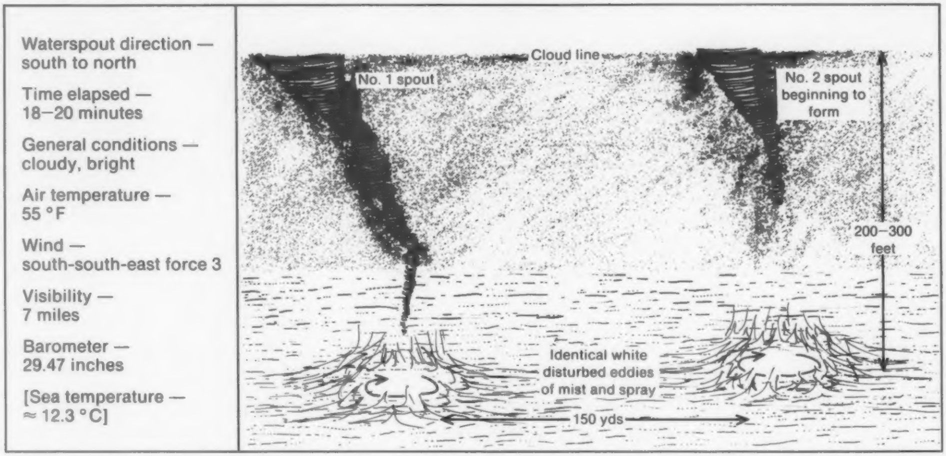
There will be sufficient free time to allow excursions to nearby places of interest.

Further particulars and application forms are available from Dr W. M. Young, 1986 Summer School Secretary, Carnegie Laboratory of Physics, University of Dundee, Dundee DD1 4HN, Scotland.

Waterspouts off the Farne Islands

The account that follows is taken from a letter to the editor from Mr Gordon Medlicott, a keeper at the Longstone Lighthouse on the Farne Islands off the coast of Northumberland. At 12 GMT on the day in question a mature depression extending up through the troposphere was slow moving off north-west Ireland with a central pressure of 984 mb. An unstable south-easterly airstream covered the area of the Farne Islands and showers were widespread over the whole of the British Isles. A thunderstorm was reported at Aberdeen at 12 GMT.

When I observed the event I was very excited to be able to witness such an event at close quarters. I have seen waterspouts in the Southern Oceans whilst in the Merchant Navy some 25 years ago but ships always give these things a wide berth and they are only seen from a distance. However here is an account of what was observed by myself and two colleagues at the Longstone Lighthouse on 2 October 1984. The general weather conditions were, a fine bright day with only a slight sea swell. Our attention was drawn by a rather unexpected heavy rain shower which lasted only about 90 seconds, it was then observed that a very black cloud was to the south of us at about 800 yds and a small disturbance was dancing on the water, this continued to grow until a large localized area of about 10–12 yards of mist and spray could be seen spinning about. We then realised we were about to see something unusual. This disturbance was of course the birth of the eventual waterspout. My colleagues went off to fetch their cameras and during the next 15–18 minutes took several shots of the event, unfortunately the resulting photographs do not show the event too well, but it was worth the attempt. A second swirl of water began to form about 150 yards south-east of the first and this did eventually form into a very thin spout, but the first one was of the main interest. The spout began to form, originating from a cone at cloud level (this was most surprising as I'd



Sketch of waterspouts observed near the Longstone Lighthouse, Farne Islands, on 2 October 1984 (drawn from a rough sketch made by the author) together with readings made at the time.

assumed they started at sea level and climbed upwards), it was now about 400–600 yards away, and we then had visible two waterspouts, these were travelling in a northerly direction (I wouldn't like to hazard a guess at the speed) and eventually disappeared. After reading up on waterspouts I now realise that what we had seen was a textbook phenomenon.

Photograph taken by Mr Turney, Assistant Keeper, of one of the waterspouts observed near the Longstone Lighthouse, Farne Islands, on 2 October 1984.

International assessment of the role of carbon dioxide and of other greenhouse gases on climate variations and associated impacts

We think our readers will be interested in the following 'conference statement' which we print as received.

A joint United Nations Environment Program (UNEP)/ World Meteorological Organization (WMO)/ International Council of Scientific Unions (ICSU) conference was convened in Villach, Austria from 9 to 15 October 1985, with scientists from 29 developed and developing countries, to assess the role of increased carbon dioxide (CO_2) and other radiatively active constituents of the atmosphere (collectively known as greenhouse gases and aerosols) on climate changes and associated impacts. The other greenhouse gases reinforce and accelerate the impact due to CO_2 alone. As a result of the increasing concentrations of greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history.

The conference reached the following conclusions and recommendations:

1. Many important economic and social decisions are being made today on long-term projects — major water resource management activities such as irrigation and hydro-power, drought relief, agricultural land use, structural designs and coastal engineering projects, and energy planning — all based on the assumption that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption since the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century. It is a matter of urgency to refine estimates of future climate conditions to improve these decisions.
2. Climate change and sea-level rises due to greenhouse gases are closely linked with other major environmental issues such as acid deposition and threats to the Earth's ozone shield, these being mostly due to changes in the composition of the atmosphere caused by man's activities. Reduction of coal and oil use and energy conservation undertaken to reduce acid deposition will also reduce emissions of greenhouse gases; a reduction in the release of chlorofluorocarbons (CFCs) will help protect the ozone layer and will also slow the rate of climate change.
3. While some warming of climate now appears inevitable due to past actions, the rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels, and the emission of some greenhouse gases.

These conclusions are based on the following consensus of current basic scientific understanding:

- The amounts of some trace gases in the troposphere, notably CO_2, nitrus oxide (N_2O), methane (CH_4), ozone (O_3) and CFCs, are increasing. These gases are essentially transparent to incoming short-wave solar radiation but they absorb and emit long-wave radiation and are thus able to influence the Earth's climate.
- The role of greenhouse gases other than CO_2 in changing the climate is already about as important as that of CO_2 itself. If present trends continue, the combined concentrations of atmospheric CO_2 and other greenhouse gases will be radiatively equivalent to a doubling of the amount of CO_2 from pre-industrial levels, possibly as early as the 2030s.
- The most advanced experiments with general circulation models of the climatic system show increases of the global mean equilibrium surface temperature for a doubling of the atmospheric CO_2 concentration, or equivalent, of between 1.5 and 4.5 °C. Because of the complexity of the climatic system and the imperfections of the models, particularly with respect to ocean–atmosphere interactions and clouds, values outside this range cannot be excluded. The realization of such changes will be slowed by the inertia of the oceans; the delay in reaching the mean equilibrium temperatures corresponding to doubled greenhouse gas concentrations is expected to be a matter of decades.
- While other factors such as aerosol concentrations, changes in solar energy input and changes in

vegetation may also influence climate, the greenhouse gases are likely to be the most important cause of climate change over the next century.

- Regional-scale changes in climate have not yet been modelled with confidence. However, regional differences from the global averages show that warming may be greater in high latitudes during late autumn and winter than in the tropics; annual mean run off may increase in high latitudes; and summer dryness may become more frequent over the continents at middle latitude in the northern hemisphere. In tropical regions, temperature increases are expected to be smaller than the average global rise, but the effects on ecosystems and humans could have far-reaching consequences. Potential evapotranspiration will probably increase throughout the tropics whereas in moist tropical regions convective rainfall could increase.
- It is estimated on the basis of observed changes since the beginning of this century, that global warming of 1.5 to 4.5° C would lead to a sea-level rise of 20–140 cm. A sea-level rise in the upper portion of this range would have major direct effects on coastal areas and estuaries. A significant melting of the west Antarctic ice sheet leading to a much larger rise in sea level, although possible at some future date, is not expected during the next century.
- Based on analyses of observational data, the estimated increase in global mean temperature during the last one hundred years of between 0.3 and 0.7° C is consistent with the projected temperature increase attributable to the observed increase in CO_2 and other greenhouse gases, although it cannot be ascribed in a scientifically rigorous manner to these factors alone.
- Based on evidence of the effects of past climate changes, there is little doubt that a future change in climate of the order of magnitude obtained from climate models for a doubling of the atmospheric CO_2 concentration could have profound effects on global ecosystems, agriculture, water resources and sea ice.

RECOMMENDED ACTIONS

1. Governments and regional inter-governmental organizations should take into account the results of this assessment in their policies on social and economic development, environmental programs, and control of emissions of radiatively active gases.
2. Public information efforts should be increased by international agencies and governments on the issues of greenhouse gases, climate change and sea level, including wide distribution of the documents of this conference.
3. Major uncertainties remain in predictions of changes in global and regional precipitation and temperature patterns. Ecosystem responses are also imperfectly known. Nevertheless, the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin an active collaboration to explore the effectiveness of alternative policies and adjustments. Efforts should be made to design methods necessary for such collaboration.

Governments and funding agencies should increase research support and focus efforts on crucial unsolved problems related to greenhouse gases and climate change. Priority should be given to national and international scientific program initiatives such as (a) the World Climate Research Programme (WMO–ICSU), (b) present and proposed efforts on biogeochemical cycling and tropospheric chemistry in the framework of the Global Change Programme proposed by ICSU, and (c) National Climatic Research Programmes. Special emphasis should be placed on improved modelling of the ocean, cloud–radiation interactions, and land surface processes.

Support for the analysis of policy and economic options should be increased by governments and funding agencies. In these assessments the widest possible range of social responses aimed at preventing or adapting to climate change should be identified, analysed and evaluated. These assessments should be initiated immediately and should employ a variety of available methods. Some of these analyses should

be undertaken in a regional context to link available knowledge with economic decision-making and to characterize regional vulnerability and adaptability to climate change. Candidate regions may include the Amazon basin, the Indian subcontinent, Europe, the Arctic, the Zambezi basin, and the North American Great Lakes.

4. Governments and funding institutions should strongly support the following:
   (i) Long-term monitoring and interpretation with state-of-the-art models of radiatively important atmospheric constituents in addition to CO_2 (including aerosols), solar irradiance, and sea level.
   (ii) Study and interpretation of the past history of climate and environment, specially regarding interactions among the atmosphere, oceans and ecosystems.
   (iii) Studies of the effects of atmospheric composition and of changing climate and climatic extremes on subtropical and tropical ecosystem, boreal forests, and on water regimes.
   (iv) Investigations of the sensitivity of the global agricultural resource base with respect to:
      (a) direct effects of increases in atmospheric CO_2 and other greenhouse gases;
      (b) effects of changes in climate; and
      (c) probable combinations of these.
   (v) Evaluation of social and economic impacts of sea-level rises.
   (vi) Analysis of policy-making procedures under the kinds of risks implied by a significant greenhouse warming.

5. UNEP, WMO and ICSU should establish a small task force on greenhouse gases, or take other measures, to:
   (i) help ensure that appropriate agencies and bodies follow up the recommendations of the conference;
   (ii) ensure periodic assessments are undertaken of the state of scientific understanding and its practical implications;
   (iii) provide advice on further mechanisms and actions required at the national or international levels;
   (iv) encourage research in developing countries to improve energy efficiency and conservation; and
   (v) initiate, if deemed necessary, consideration of a global convention.

Presentation of award to Sir Arthur Davies

Sir Arthur Davies, KBE, Secretary-General Emeritus of the World Meteorological Organization (WMO), was presented with the thirtieth International Meteorological Organization (IMO) Prize on 20 January 1986 at a ceremony held at the premises of the Royal Society, London. (See *Meteorol Mag*, **114**, 1985, 323.) The proceedings were opened by the Parliamentary Under-Secretary of State for Defence Procurement (Mr John Lee, MP) who spoke of Sir Arthur's achievements and gave official expression of the pleasure of HM Government that Sir Arthur had been honoured in this way. Professor G.O.P. Obasi, the current Secretary-General of WMO, outlined the history of the IMO Prize and gave an account of Sir Arthur's career including personal memories of the latter's courtesy and helpfulness. Both Mr Lee and Professor Obasi referred to the remarkable fact that the United Kingdom had already provided four recipients of the IMO Prize, and said how pleased they were that two of this number — Professor R.C. Sutcliffe and Mr J.S. Sawyer — were present at the ceremony. Dr R.L. Kintanar, President of the WMO, then formally presented the Prize to Sir Arthur Davies.

In his speech of thanks, Sir Arthur said how privileged he felt to have his name added to the list of distinguished scientists from all over the world who had been similarly honoured, and himself paid tribute to the presence of Dr Sutcliffe and Mr Sawyer. He stressed the importance of the international and co-operative nature of meteorological science, of which the IMO Prize was itself a symbol.

Sir Arthur Davies receiving his award from Dr R.L. Kintanar.

Letter to the Editor

Comments on 'Satellite photograph — 4 November 1985 at 0426 GMT' (*Meteorol Mag*, **115**, 1986, 34–35): the explanation of the obscure streak in the middle of the clear area off southern Iceland.

An analysis of 20 synoptic observing stations over Iceland at 00 and 09 GMT on 4 November suggests that the origin of the streak is due to low-level convergence near and off the coast of south-east Iceland. Coastal observations along the east and south-east coasts suggest that the north-easterly air flow splits on approaching Iceland, the bulk of the flow passing south-east of the land mass and blowing strongly along the south-east coast. However, part of the flow crosses the land to go round the northern part of the vast upland ice sheet Vatna Jökull (mostly 1000 to 2000 m above sea level) before turning south to reach the south coast of Iceland in the region of the cloud streak. Additionally, it is possible that a strong katabatic from the ice sheet also aids the northerly flow off the land in that area. Thus, as shown in Fig. 1, there is marked surface convergence in the region of cloud formation. Interestingly, surface observations also suggest a second convergence line originating near the eastern-most tip of Iceland, and extending downstream. Close examination of the satellite picture does suggest a continuous line of cloud corresponding to this convergence zone.

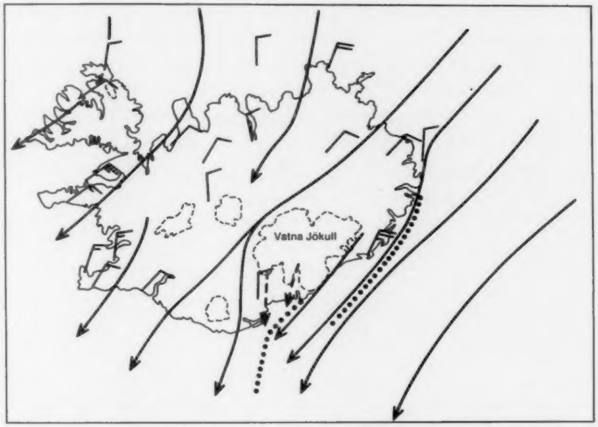


Figure 1. Surface wind direction and speed (one long feather = 10 kn) and streamlines at 09 GMT 4 November 1985. Significant ice sheets are depicted by pecked lines, these generally covering high ground above about 800–1000 m. The convergence zones referred to in the text are shown by dots and the katabatic flow from the Vatna Jökull ice sheet by dashed lines.

Cloud bands such as these are frequently seen in satellite imagery when cold air masses stream out to sea in regions where the immediate land area is hilly or where there are distinct kinks in the coastline. Such bands have been documented by Mass and Dempsey (A topographically forced convergence line in the lee of the Olympic mountains, *Mon Weather Rev*, 1985, **113**, 659–663) when cold air streams westwards into the Pacific from Washington State. Readers may even spot such bands over the British Isles, notably in north-westerly airstreams when cold air reaches the Irish Sea from the region of the Mourne Mountains (County Down), and also over the North Sea downwind from the Aberdeen or Berwick-upon-Tweed (Northumberland) areas.

G.A. Monk

Meteorological Office
Bracknell

Reviews

The climatic scene, edited by M.J. Tooley and G.M. Sheail. 155 mm × 240 mm, pp. xxi + 306, *illus.* George Allen and Unwin, London, Boston, Sydney, 1985. Price £23.00.

In his opening lectures to postgraduate courses at Imperial College in the mid-1950s Professor Sheppard used to say that meteorology was an observational science. That was, of course, before the advent of large computers and the development of dynamical modelling techniques transformed a major part of the subject. Nowadays, major advances in the understanding of the atmosphere can come from, often unsung and by many people not understood, formulations or reformulations of sets of equations or improvements in the parametrization for numerical modelling purposes of the physical processes that dominate atmospheric dynamics.

To many young, and perhaps not so young, meteorologists, even to discuss the accomplishments and achievements of Gordon Manley may seem anachronistic and those who bother to read his papers may all too easily dismiss them as being the speculative writings of a geographer somewhere on the fringes of meteorology. What then did Manley achieve? Why should his memory and work be honoured by a distinguished group of meteorologists, climatologists and biometeorologists? In a very few words, Manley simply made maximum effective use of the main tools available to meteorologists of his era. He observed and recorded what he saw perceptively, he described accurately and, above all, he understood much of what he saw. He concentrated much of his interest upon geographical and topographical variations of the weather within the United Kingdom and, particularly, over and around his much loved Pennines. Although essentially empirical, his work on lee waves — especially that particular phenomenon known as the helm wind of Crossfell — was the springboard from which the definitive theoretical contributions by R.S. Scorer and others gained much of their impetus. As a meteorological journalist Manley stood the critical test of the *Manchester Guardian* (nowadays *The Guardian*) editorship and readership.

Manley graduated, first, as an engineer and then proceeded to read for a degree in geography at Cambridge. There, his boyhood interest in meteorology began to bloom when he was introduced to polar and high-level environmental problems. His engineering training gave him the feel for basic and accurate measurements while his Cambridge studies indicated how this might best be applied to his particular interests.

This book in paying tribute to Manley discusses and extends his work in various fields. In order to determine whether or not climatic changes are occurring or have occurred during the few centuries when instrumental observations are available it is necessary to be able to compare past and present data. Such procedures are bedevilled by changes in instruments, instrument exposures, sites, observing practices, and so on. A major and important component of his work is the creation of homogeneous data sets such as the Central England Temperature Series.

After a brief biography of Manley, three chapters by Kenworthy, Harris and Shaw discuss the creation and use of such homogenized data series for the United Kingdom. Flöhn discusses the derivation of proxy series — a technique that owes much to Manley. Lamb also shows how proxy data can be used and produces synoptic maps for some famous historic storms. Notable must be that for the Spanish Armada in 1588 for which Lamb has produced charts of isobars and fronts before the barometer was even invented!

Chapters by Grove and Pfister discuss such matters as snow cover and glaciers over Scandinavia and central Europe, subjects both dear to Manley's heart. Long-term climatic changes are discussed by Barber in a study of peat stratigraphy. Oldfield and Robinson discuss geomagnetism and palaeoclimate while the last three chapters in the book all point to the reasons for investigating climate and climatic change at all. Tooley discusses sea-level and coastal changes, Carter and Prince discuss the effects of climate on plant distributions while Bourke writes about climatic effects on diseases and pests of agriculture. These last three papers would have been received by Manley with particular enthusiasm. He was always aware of the principal reasons for studying climate as shown by his contributions to the *Report of the land utilisation survey of Britain.*

In these days of sophisticated climatic modelling it could be very easy for the incautious to derive solutions for the many integrations of sets of equations but yet have no idea either as to the likelihood of occurrence or the consequential effects upon humanity. There is a need for the type of work undertaken by Manley to continue, a need to be able to validate data whether these are derived from current observations, proxy historical or model output. There is a need to be able to understand the possible effects of climatic change. The economic and social consequences of not so doing could be traumatic.

We owe it to future generations — and no one as yet knows just how far in the future — to understand the atmosphere and, particularly, its long-term variability.

This book should be read by all those, of whatever meteorological discipline, who are striving to understand climate. May the work of Manley, all he stood for as a meteorologist and as a warm, understanding, concerned human being, continue to prosper.

F. Singleton

Atmospheric ozone, edited by C.S. Zerefos and A. Ghazi. 155 mm × 230 mm, pp. xxxi + 842, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, 1985. Price Dfl 275, US $99.00, £69.95.

International Ozone Symposia have been held every four years since the International Geophysical Year, the first being at Albuquerque in 1964. There has been a considerable expansion in (and funding for) atmospheric ozone research since the publication of papers in the early 1970s suggesting that there could be a reduction in stratospheric ozone as a result of man's activities. The decrease in the number of papers, from 185 in 1980 to 138 in 1984, probably reflects the decision of the organizers to restrict the sessions to four and a half days rather than five.

The papers are photographically reproduced with some reduction in size from the author's camera-ready copy, to form a single manageable volume. Rather little editing or sub-editing seems to have been done so that, in the paper by Evans *et al.* (page 680) on the use of the automated Brewer ozone spectrophotometer to produce whole-sky maps of ultraviolet intensity, the text refers to the colours used for shading, and makes quite a point of their spectral order, while the figures (obviously produced on the same PET microcomputer) use 'chunky' graphic symbols in black and white. Again, on page 583, N^z is printed where N^2 was clearly intended, and on pages 256 and 257 Figs 1 and 3 have been interchanged. In view of the method of reproduction, it could be argued that the fault lies more with the authors than with the editors, but it remains a fault. With the exception of just two one-page abstracts, the contributions are presented as short papers of between two and six pages. The actual variation in content of the work presented is far greater than this — while some papers might have appeared elsewhere as letters others are in effect extended abstracts of much larger papers, even though formally they forego the claim to *be* abstracts by *having* them. Both types of presentation are useful, and it is convenient to have them assembled in one place.

The topics covered by the papers largely follow the pattern set by previous Ozone Symposia, and the reader desiring an outline of each of the nine sessions will find the Editors have provided just that in their introduction. I shall confine myself to noting what seemed to me to be the main areas of growth. In 1980 there was just one paper reporting preliminary results with the Total Ozone Mapping Sounder (TOMS), and more on the nadir-viewing Solar Backscattering Ultraviolet (SBUV) instrument. In 1984 the Symposium heard reports of improved algorithms for calculating total ozone columns from TOMS and SBUV, and vertical profiles from SBUV. An extensive set of maps of total ozone is available from TOMS, and has been used to check the ground-based ozone spectrophotometer network. The relationship between upper-atmosphere circulation patterns and total ozone as observed by Dobson decades ago is now seen in far greater detail. Difficulty in reconciling TOMS and SBUV values with the Dobson network has resulted in a number of new determinations of the absorption cross-section of ozone, which seem to have largely removed the disparity. The essentially downward-looking infra-red and ultraviolet satellite instruments have been joined by a new generation which view the Earth's limb, using either thermal emission (Limb Interferometer Monitor of the Stratosphere and the Stratosphere Mesosphere Explorer) or solar occultation (Stratospheric Aerosol and Gas Experiment). These are able

to measure other minor species of importance in ozone photochemistry, as well as ozone. As far as computer modelling is concerned, the move away from one-dimensional models to two and three dimensions has continued. Two major balloon measurement programs aimed at comparing different measurement techniques for both ozone and related minor species are reported. They are the Balloon Intercomparison Campaign, in Texas in 1982, and the Middle Atmosphere Program/Globus, at Aire-sur-l'Adour in 1983. Finally there was an increase in the number of papers on ozone in the troposphere, even though the section heading implies that papers on polluted urban atmospheres had been excluded. The general impression is of an area of research which is active within its own borders and a stimulus to neighbouring areas.

E.L. Simmons

Global change, edited by T.F. Malone and J.G. Roederer. 180 mm × 252 mm, pp. xxviii + 512, *illus*. Cambridge University Press, Cambridge, London, New York, New Rochelle, Melbourne, Sydney, 1985. Price £35.00, US $59.50.

This volume, published on behalf of the International Council of Scientific Unions (ICSU), comprises the proceedings of a multi-disciplinary symposium held in Ottawa in September 1984. The specific objective of both the symposium and this book was to explore the need for, and the possibility of, an international research program 'to illuminate the complex and synergistic physical, chemical and biological processes in the Sun–Earth system that determine its change'. As with so many recent environmentally-orientated proposals, the underlying justification is posed in terms of pressures both from society and upon society. However, although the preface quotes with approval from the ICSU General Assembly of 1982 that 'This will not only present a challenge to all the disciplines now represented in ICSU but will require increasing contact with the human and social sciences', there is limited evidence of such societal-based contact — the final paper on human activities and global change (W.C. Clark and C.S. Holling) plus 2½ pages from R.W. Kates as 'extended comment'.

The book is thus a statement of the science involved in such a geosphere–biosphere program, and is structured to provide authoritative summary reviews on the major areas of concern. After four general policy-type presentations, there follows a section on the atmosphere and hydrosphere (although the latter does not seem to involve hydrology!). The structure of this section is not too clear, however. Following papers on atmospheric chemistry (P.J. Crutzen and M.O. Andreae) and physics (G.S. Golitsyn), there is a brief review of recent global climatic change studies presented by T. Yeh and C. Fu. Then two papers introduce the role of the oceans and their interaction with the atmosphere (R.W. Stewart and F.B. Bretherton, and D. Lal and W.H. Berger), before returning to the climatic change theme again with an account of the World Climate Research Programme by its Director, P. Morel. This section concludes with what to the reviewer was the most stimulating contribution, namely a palaeoclimatic research plan by T. Webb, J. Kutzbach and F.A. Street-Perrott. For atmospheric scientists this section overall provides a useful review of ongoing enquiries in areas with which one is, in general, familiar. The critical issue, however, is its impact on other scientists, as it is interaction and integration of research interests and understanding which is the whole purpose of the exercise.

For atmospheric scientists, therefore, the major value should be in the succeeding sections — seven papers on life systems, two on the solid earth, and four on sun and space. It is at this stage that the very real diversity of interests, objectives and expertise involved becomes apparent to any reader. Individuals will find different sections the most stimulating and informative — the several papers on ecosystems

appealed most to this reviewer. Critical gaps also appear, such as virtually no reference to change in the detailed form of the land surface itself, i.e. the whole field of geomorphology.

There is then a brief section on the theme of tools and technology, which may well prove to be the most critical theme if integrated work at a truly global scale is to be attempted seriously. As a result, merely two fairly brief papers on monitoring change by satellites (S.I. Rasool) and on data management (W.W. Hutchinson and S.W. Bie) seemed to under-represent the vital role that these areas must play, though there is also a valuable extended comment on a world digital data base by D.P. Bickmore. Finally, an equally brief section of human activity is still partially concerned with the impact of society on the science of the environment, so that the critical issue of society's ability to adjust to change receives scant attention — despite the incontrovertable assertion that 'managing global change is not the same as predicting it' (p. 478).

Overall, this volume is both stimulating and disappointing. All readers will find informed guidance to ideas and developments beyond, yet essentially related to, their own area of interest and expertise. Yet the evidence of real research integration — as distinct from assertions of faith — is not as great as one might have hoped. Perhaps the very existence of this volume, and the encouragement for integration from ICSU that it implies, will enable such integration to develop further.

S. Gregory

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Reviews of United Kingdom statistical sources, Vol. XVII; Weather, by B.W. Atkinson, and *Water,* by E.C. Penning-Rowsell and D.J. Parker for the Royal Statistical Society and the Economic and Social Research Council (Oxford, Pergamon Press, 1985. £27.00) is the latest volume in this series, which details the availability and form of statistical information on a wide variety of topics. The primary aim of the series is to act as a work of reference to the sources of statistical material of all kinds, both official and unofficial. This volume covers the availability (or otherwise) of a wide variety of meteorological and hydrological data sources.

Safety of dams: flood and earthquake criteria, by the Committee on Safety Criteria for Dams, the Water Science and Technology Board, the Commission on Engineering and Technical Systems, and the Natural Research Council (Washington, National Academy Press, 1985. £18.50) is a report concerning the levels of safety to be provided at dams to withstand extreme floods and earthquakes. In the opening chapter of the book an attempt is made to take a broad look at the problems of coping with extreme floods and earthquakes at dams from the viewpoint of society as a whole. Other chapters describe the technical methods that have evolved to estimate the magnitude of extreme floods and earthquakes, the limitations of the methods, and some possible improvements in the methods.

Sea fog, by Wang Binhua (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1985. DM 215) describes many aspects of sea fog, with particular reference to fogs over the East Asia Sea region. The author started compiling and summing up the materials and experience concerning sea fog as far back as the 1940s. In recent decades data from marine meteorological observatories, research ships and, in particular, meteorological satellites have made possible the development of a general concept for sea fog distribution and the mechanisms of its generation and dissipation. The present book contains chapters

on the generation and classification of sea fog, its distribution and variations around the world, hydrometeorological characteristics, sea fog analysis in the East Asia Sea region, the physical properties of sea fog, and sea fog forecasting.

Ice shelves of Antarctica, by N.I. Barkov (Rotterdam, A.A. Balkema, 1985. Hfl.85.00, £20.75) examines the large volume of observational data collected and published by the many expeditions to Antarctica before 1968. The author describes the special conditions of existence of ice shelves, their movement, morphology, charging, the structure of the thermal regime, and their contribution to the development of glaciation on the continent. Particular attention has been paid to the study of the floating, most representative, part of such ice formations. Considerable space has been devoted to the author's own observations made during 1960–61 in the West, Shackleton, Lazarev and Novolazarevskii ice shelves when he was a member of the glaciological section of the Fifth Soviet Antarctic Expedition.

Atmospheric chemistry and physics of air pollution, by John H. Seinfeld (Chichester, John Wiley and Sons, 1986. £61.35) is intended to serve as a textbook for a course in the atmospheric aspects of air pollution. Its object is to provide a rigorous, comprehensive treatment of the chemistry of air pollutants in the atmosphere, the formation, growth, and dynamics of aerosols, the meteorology of air pollution, and the transport, diffusion, and removal of species in the atmosphere.

World survey of climatology, Vol. 1A: General climatology, by A. Kessler (Amsterdam, London, New York, Tokyo, Elsevier Science Publishers, 1985. US $55.50, Dfl. 150.00) summarizes the current knowledge of the heat and radiation budget of the Earth's surface and includes many of the important contributions made in the last decade. The text is, however, more than just a summary as the author has taken into consideration the climatological impact of the budget, thus providing a particularly profound treatment of the topic.

Mr G.A. Bull

We record with regret the death on 27 February 1986 of Mr G.A. Bull who was Editor of the *Meteorological Magazine* from 1947 to 1960. He joined the Office in 1926 and, after the usual early career in forecasting, both before and during the war, began his long association with the National Meteorological Library and the Editing Section. From 1953 to 1959 he was the United Kingdom member of the World Meteorological Organization Technical Commission on Bibliography and Publications and was for some time the Vice-President of the Commission. He played a major part in planning the Library at Bracknell and in setting up the Meteorological Office Technical Archives as a consequence of the Public Records Act of 1958. In 1960 he was promoted to Assistant Director (Support Services), later becoming Assistant Director (Data Processing).

He was Honorary Librarian of the Royal Meteorological Society from 1960 to 1964. After retiring from the Office in 1966 Mr Bull became Administrative Secretary of Reading University Library, an appointment he held for the next two years.

Mr Bull will be remembered by all his colleagues as a friendly, enthusiastic and hard-working man who won the respect of all who knew him. He, more than anyone else, made the *Meteorological Magazine* what it is today.

Meteorological Magazine

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe the results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles for publication and all other communications for the Editor should be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For *Meteorological Magazine*'.

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately.

Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

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